IMPACT OF ELEVATION AND ASPECT ON THE SPATIAL DISTRIBUTION OF VEGETATION IN THE QILIAN MOUNTAIN AREA WITH REMOTE SENSING DATA

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ABSTRACT:

The spatial distribution of vegetation in the Qilian Mountain area was quantified with remote sensing data. The MODIS NDVI values for June, July, August and September are the best indicators for the vegetation growth during a year in this area and thus were used in this study. The results obtained by analyzing the NDVI data for seven years from 2000 to 2006 clearly indicated that elevation is the dominating factor determining the vertical distribution of vegetation in the area: the vegetation growth is at its best between the elevations of 3200 m and 3600 m with the NDVI values lager than 0.5 and a peak value of larger than 0.56 at 3400 m. The horizontal distribution of vegetation within the zone of 3200 m and 3600 m is significantly impacted by the aspect of hillslopes: the largest NDVI value or the best vegetation growth is found in the shady slope whose aspect is between NW340º to NE70º due to relatively less evapotranspiration. The methodology developed in this study should be useful for similar ecological studies related to vegetation distribution.

1. 1 INTRODUCTION

The vegetation cover in mountain areas is very important. Vegetation cover affects local and regional climate and reduce erosion. Economy of local communities and millions' people in mountain areas depends on forests and plants. They also effectively protect people against natural hazards such as rockfall, landslides, debris flows, and floods (Brang et al., 2001). Settlements and transportation corridors in alpine regions mainly depend on the protective effect of the vegetation (Agliardi and Crosta, 2003). Therefore, understanding of distribution and patterns of vegetation growth along with the affecting factors in those areas are important and have been studied by many researchers (Oliver and Webster 1986; Weiser et al. 1986; Stephenson 1990; Turner et al. 1992; Henebry 1993; Endress and Chinea 2001; Bai et al. 2004).

Topography is the principal controlling factor in vegetation growth and that the type of soils and the amount of rainfalls play secondary roles at the scale of hillslopes (O'Longhlin 1981; Wood et al. 1988; Dawes and Short 1994). Elevation, aspect, and slope are the three main topographic factors that control the distribution and patterns of vegetation in mountain areas (Titshall et al. 2000). Among these three factors, elevation is most important (Day and Monk 1974; Busing et al. 1992). Elevation along with aspect and slope in many respects determines the microclimate and thus large-scale spatial distribution and patterns of vegetation (Geiger 1966; Day and Monk 1974; Johnson 1981; Marks and Harcombe 1981; Allen and Peet 1990; Busing et al. 1992).

One of the powerful tools to study the spatial distribution of vegetation is remote sensing. Remote sensing has traditionally been used in large-scale global assessments of vegetation distribution and land cover with the Normalized Difference Vegetation Index (NDVI) data from Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) (Chen and Brutsaert 1997; Defries and Townshend 1994; Defries et al. 1995; Friedl et al. 2002; Loveland et al. 2000, 1999). The NDVI is an index derived from reflectance measurements in the red and infrared portions of the electromagnetic spectrum to describe the relative amount of green biomass from one area to the next (Deering 1978). The NDVI is an indicator of photosynthetic activity of plants and has been widely used for assessing vegetation phenology and estimating landscape patterns of primary productivity (Sellers, 1985; Tucker and Sellers, 1986). It was designed to quantitatively evaluate vegetation growth: higher NDVI values imply more vegetation coverage, lower NDVI values imply less or non-vegetated coverage, and zero NDVI indicates rock or bare land.

Most studies with remote sensing data were concentrated on two-dimensional horizontal patterns and a few were focused on the effect of elevation on the vertical distribution of vegetation in mountain areas (Franklin 1995; Edwards 1996; Guisan and Zimmermann 2000; Hansen 2000; Miller et al. 2004). The objectives of this study are two-fold: 1) to quantitatively assess both vertical and horizontal distribution of vegetation in the Qilian Mountain area and its main controlling factors, i.e., elevation, aspect, and 2) to demonstrate the usefulness of the methodology which may be used for other environmental and ecological studies.

2. STUDY AREA

Located in the upstream of the Heihe River basin, the Qilian Mountain area has a steep topography with an elevation range from 1680 m to 5100 m (Figure 1). The intermountain basin and longitudinal valley are widely developed in the area. The northern part of the Qilian Mountain surrounded by tributaries of Heihe River to the east and west was selected to be the study area (the area outlined with the bold black line in Figure 1) because this area represents a typical mountain range and best reflects the vegetation change with elevation. The total study area is 2968 km2. The climate in this area is characterized by typical high plateau continental climate. The average annual temperature is 0.6 ℃ and the amount of precipitation increases with the elevation. Due to complex topography, the climate is diverse and has distinct vertical characteristics. These vertical climate characteristics have important impacts on the soil development and vegetation growth in the areas as they do in many other mountains.

The vegetation distribution in this area exhibits an obvious vertical gradient due to the climatic changes with elevation. The vegetation types from the low altitude to high altitude are: desert-grassland vegetation (1800–2100 m), dry shrub-grassland vegetation (2100–2400 m), mountain forest-grassland vegetation (2400–3400 m), sub-alpine shrub-grassland vegetation (3400–3900 m), and cold-desert alpine meadow vegetation (>3900 m). The mountain forest-grassland vegetation is the main vegetation type and the main component of the Qilian Mountains ecosystem. The range of elevations (1800–5100 m) in study area was divided into a total of 31 intervals with 100m in each of the intervals and the aspect angle was divided into a total of 72 intervals with 5º in each of the interval.

The vegetation in the Qilian Mountain area plays an important role in the local water cycle by affecting hydrological processes, e.g., evapotranspiration and runoff, and is an important ecological storage for water resources. Qilian Mountain supplies water for Hexi Corridor which is the most important agricultural region and settlement in northwest China. The vegetation in the Qilian Mountain area significantly affects the oasis system in the region and protects the middle and downstream area of Heihe River against desertification.

3. DATASET

The MODIS NDVI data, the vegetation index maps depicting spatial and temporal variations in vegetation activities, is derived by precisely monitoring the Earth’s vegetation. These vegetation index maps have been corrected for molecular scattering, ozone absorption, and aerosols. The MODIS NDVI data is based on 16-day composites and its spatial resolution is 250 m. Currently, the MODIS NDVI products have been used throughout a wide range of disciplines, such as inter- and intra-annual global vegetation monitoring climate and hydrologic modeling, and agricultural activities and drought studies (Zhan et al. 2000; Jin and Sader 2005; Sakamoto et al. 2005; Knight et al. 2006; Lunetta et al. 2006). In this study the NDVI values from 28 MODIS NDVI images of the 16-day composites of June, July, August and September in seven years from 2000 to 2006 were used to study the spatial distribution of vegetation in the northern part of the Qilian mountain area because June, July, August and September are the most productive months of vegetation growth during a year and thus the NDVI values of these four months can best reflect the pattern of the vegetation cover in the region.

The Digital Elevation Model (DEM) data was downloaded from the Digital River Basin website (http://heihe.westgis.ac.cn) and its spatial resolution is 100 m. The MODIS NDVI was resampled and interpolated to have the same spatial resolution as the DEM data in this study.

4. RESULTS AND DISCUSSION

It is well known that spatial distribution of vegetation cover is usually affected by elevation and aspect. Most vegetation in the northern part of Qilian Mountain area is distributed between the elevations of 1800 m and 4500 m. To the best of our knowledge, however, the obvious spatial distribution and patterns have not been studied quantitatively. We show in this study that the readily available NDVI data can be used to quantify the spatial distribution of vegetation. The range of elevations from 1800 m and 4500 m was divided into a total of 270 intervals with 10m in each intervals. The aspect angle of 360º were divided into a total of 72 intervals with 5º in each intervals. These divisions result a total of 19360 cells among which 19060 cells with the NDVI values larger than zero. In each cell the NDVI values from year 2000 to 2006 were averaged. The mean values represent the general conditions of vegetation growth in different elevations and aspects. A contour map of the mean NDVI values with elevation and aspect in the northern part of Qilian Mountain was plotted in Figure 2. A Gaussian smooth filter was used and a low pass convolution was performed on the gridded data to obtain the more consistent and smooth map in Figure 2.

Several observations can be made in Figure 2 regarding the effects of elevation and aspect on the vegetation growth in the mountain area. First of all, it is clearly seen that the elevation is the main controlling factor in the vegetation growth. The NDVI value increases with the elevation and reaches its maximum value around 3400 m and then decreases as the elevation increases beyond 3400 m. The NDVI value is mostly larger than 0.50 (the dark green region in Figure 2) when the elevation is between 3200 m and 3600 m which is the best vertical zone in terms of vegetation growth. The NDVI values are less than 0.50 when the elevation is lower than 3200 m and higher than 3600 m or the vegetation growth is poorer in these elevations that in the zone of 3200 m and 3600 m.

Secondly, the vegetation growth in the Qilian Mountain area is significantly affected by aspect. The impact of aspect on the vegetation growth is most significant in the vertical zone of 3200 m and 3600 m. The best vegetation in this zone is distributed between NW340º and NE70º (the darkest green area in Figure 2 with the NDVI value larger than 0.56). In other words, the best vegetation growth is on the shady side of the mountain where much less evapotranspiration (ET) is expected. The reduced ET on the shaded side is important for the vegetation growth in the Qilian Mountain area since it is located in a semi-arid region. It is also observed in Figure 2 that a better vegetation growth occurs over a larger elevation range on the side facing north and northeast. At the aspect of N0º, for example, the NDVI value of 0.50 or larger are observed over the vertical zone of 600 m between the elevation range of 3100 m～3700 m while at the aspect of S180º the same NDVI values are observed in a smaller range 400 m between 3200 m and 3600 m. The much wider vertical zone with better vegetation growth on the shady side of Qilian Mountain may significantly affect the local water cycle and climate.

Third observation made in Figure 2 is the rate of change in the NDVI values with elevation. This rate varies more gently at lower elevations from 2000 m to 3400 m and it changes more quickly when elevation is higher than 3400 m, implying that the vegetation growth is more sensitive in high altitude area. On the average, for example, it takes about 300 m (roughly from 2600 m to 2900 m) for the NDVI value to change from 0.3 to 0.4 at the lower altitude zone and only about 200 m at the higher altitude zone.

The NDVI values corresponding to the same elevation were averaged in order to clearly show the relationship between the vegetation growth and elevation. A total of 221142 pairs of NDVI and elevation were obtained based on the 28 MODIS NDVI images of the 16-day composites of June, July, August and September in seven years from 2000 to 2006. The relationship between the averaged NDVI and elevation for the study area is clearly shown in Figure 3: the averaged NDVI increases with elevation and reaches its maximum value of about 0.56 at 3400 m and then decreases as the elevation increases beyond 3400 m, an clear indication that the vegetation growth is at its best at the elevation of 3400 m.

The effect of aspect on the vegetation growth is more clearly demonstrated in Figure 4 where the change of the NDVI values with aspect between the elevations of 3200 m and 3600 m was plotted. It is seen in Figure 4 that the NDVI value is larger than 0.55 or the vegetation growth is best in the aspect range of NW340º to NE70º and the NDVI value is less than 0.54 or the vegetation is worse between E90º to W270º. As we discussed above, this shows that the aspect of the mountain slopes significantly affects the vegetation growth in the study area. In general, the vegetation coverage on the sunny side in the semi-arid Qilian mountain area is less developed than that on the shady side because of more evapotranspiration in the sunny side than in the shady side due to the differences in their solar radiation and higher land surface temperature.

5. CONCLUSIONS

The spatial distribution of vegetation in the Qilian Mountain area was quantified with remote sensing data. The MODIS NDVI values for June, July, August and September are the best indicators for the vegetation growth during a year in this area and thus were used in this study. Based on the results obtained by analyzing the NDVI data for seven years from 2000 to 2006, the following important conclusions can be drawn.

1) Elevation is the dominating factor determining the vertical distribution of vegetation in the Qilian Mountain area: the vegetation growth is at its best between the elevations of 3200 m and 3600 m with the NDVI values larger than 0.50 and a peak value of larger than 0.56 around 3400 m.

2) The horizontal distribution of vegetation within the elevation range of 3200 m and 3600 m is significantly impacted by the aspect of hillslopes: the best vegetation growth is found in the shady slope between NW340º to NE70º with the largest NDVI value (>0.56) due to relatively less evapotranspiration.

3) Better vegetation growth occurs over a larger elevation range on the shady than sunny side because of less ET in the former than in the latter.

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FIGURE CAPTIONS

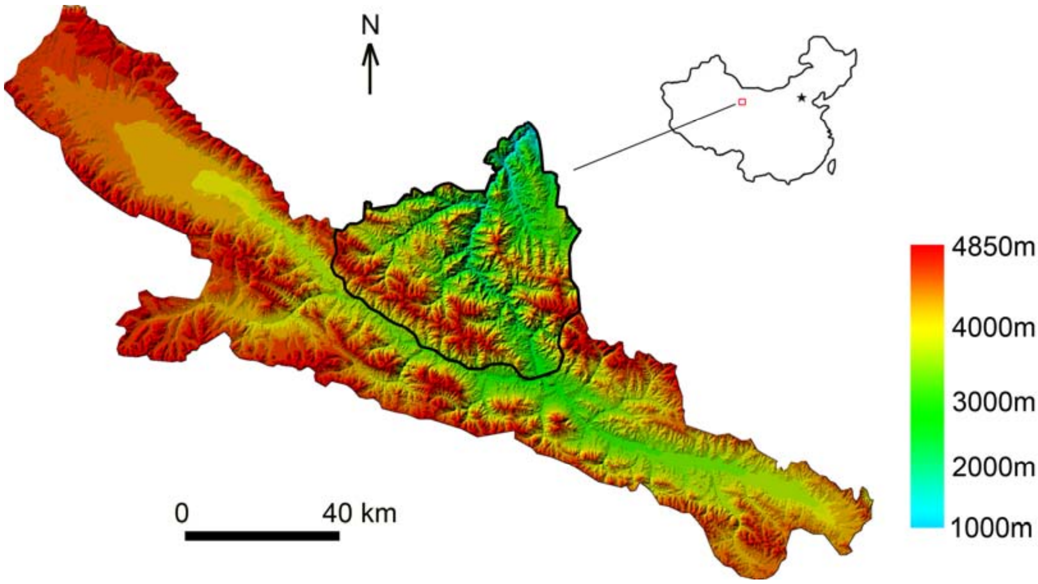

Figure 1 The DEM (digital elevation model) map of the Qianlian Mountain area with the spatial resolution of 100 m. The area surrounded by watershed of Heihe tributaries in east and west boundary (outlined with bold black line) was selected as the study area.

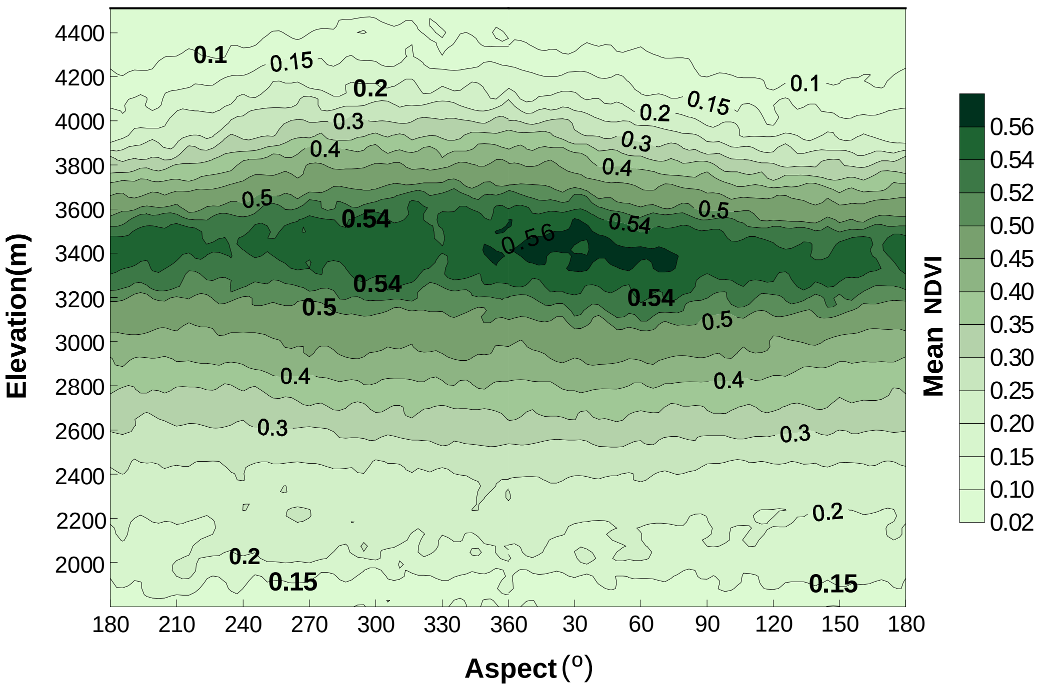

Figure 2 The change of the mean NDVI values with elevation and aspect in the northern part of Qilian Mountain. A Gaussian smooth filter was used and a low pass convolution was performed on the grid data to present a more consistent and smooth map. Note: a refiner scale (0.02) was used when the NDVI value is larger than 0.5.

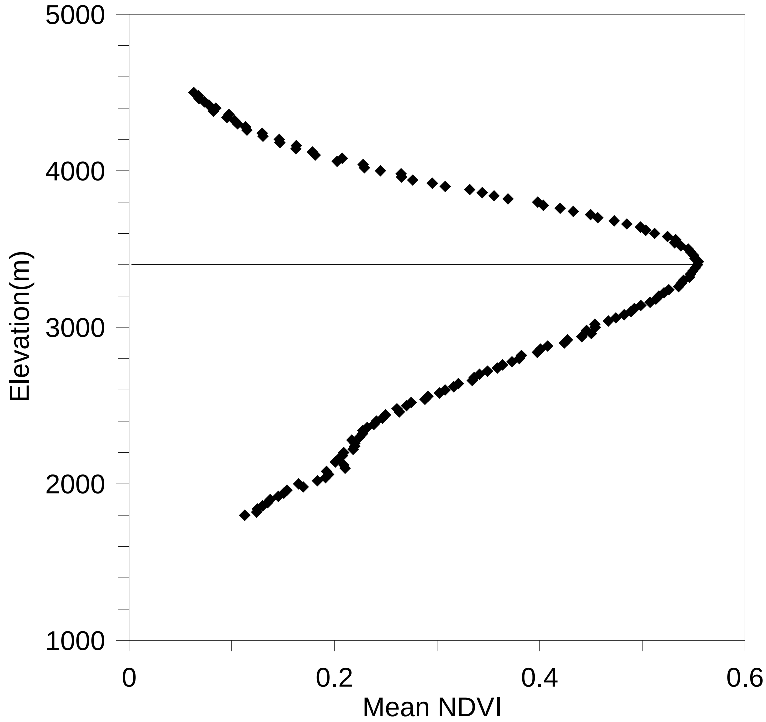

Figure 3 The change of the NDVI values with elevation in the northern part of Qilian Mountain area.

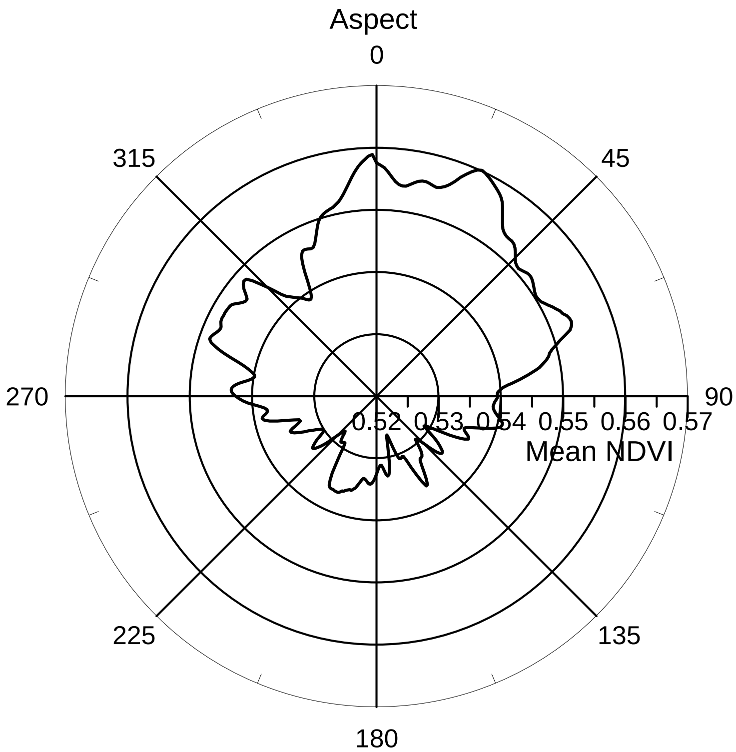

Figure 4 The change of the NDVI value with aspect for the elevation range of 3200 m to 3600 m in northern part of Qilian Mountain area.